CSIRO PUBLISHING
www.publish.csiro.au/journals/trj *The Rangeland Journal*, 2008, **30**, 291–295

Feasibility of using template-based and object-based automated detection methods for quantifying black and hybrid imported fire ant (*Solenopsis invicta* and *S. invicta* × *richteri*) mounds in aerial digital imagery

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Abstract. Imported fire ants construct earthen nests (mounds) that exhibit many characteristics which make them potentially good targets for remote sensing programs, including geographical orientation, topography, and bare soil surrounded by actively growing vegetation. Template-based features and object-based features extracted from aerial multispectral imagery of fire ant infested pastures were used to construct classifiers for automated fire ant mound detection. A classifier constructed using template-based features alone yielded a 79% probability of detection with a corresponding false positive rate of 9%. Addition of object-based features (compactness and symmetry) to the classifier yielded a 79% probability of detection with a corresponding false positive rate of 4%. Maintaining a 79% detection rate when applying the classifier to a second, unique pasture dataset with different seasonal and other environmental factors resulted in a false positive rate of 17.5%. Data demonstrate that automated detection of mounds with classifiers incorporating template- and object-based features is feasible, but it may be necessary to construct unique classifiers on a site-specific basis.

Additional keyword: classification.

Introduction

The black imported fire ant (*Solenopsis richteri* Forel) was introduced accidentally from South America around 1918 in Mobile, Alabama, followed by the red imported fire ant (*S. invicta* Buren) in 1929 (Lofgren 1986). For the purposes of this paper, these imported species and their hybrid will hereafter be referred to as IFAs. In certain agroecosystems, IFAs may prey on key insect pests, such as the sugarcane borer [*Diatraea saccharalis* (Fab.)] in sugarcane (Showler and Reagan 1991) and boll weevil (*Anthonomus grandis* Boheman) in cotton (Fillman and Sterling 1985). In many cases, however, IFAs are serious pests due to their stinging behaviour and interference with human activities, damage to electrical and agricultural equipment, and costs incurred for their control. An economic assessment in Texas estimated statewide losses to the agricultural sector exceeding US $90 million annually, and costs in the combined urban areas of Austin, Dallas, Fort Worth, San Antonio, and Houston were estimated to exceed US$580 million annually (Lard *et al*. 2001). In Australia, negative impacts of IFAs range from threats to ecological balance and native wildlife (Nattrass and Vanderwoude 2001; Moloney and Vanderwoude 2002) to human health (Solley *et al*. 2002). The IFAs currently infest over 121 million ha in the USA, ranging from coastal North Carolina to west Texas, with isolated infestations in New Mexico and California (USDA-APHIS 2007) with the potential to expand their range, especially along the west coast into Oregon (Korzukhin *et al*. 2001). For a recent review of IFA history and impact, see Tschinkel (2006) and references therein.

Imported fire ants are true mound-builders, which comprise some 10 genera in three subfamilies of ants (Hölldobler and Wilson 1990). Although many ant species construct simple underground nests with an entrance hole surrounded by excavated material, mound-building ants construct specialised above-ground structures permeated by galleries in which the colony can seek out areas of favourable temperature. Mounds vary widely in size, ranging from only a few cm across to >1 m wide and >0.3 m high. Fire ant mounds are a common sight in south-eastern USA pastures and other open areas (Fig. 1). Quantifying fire ant infestations typically involves counting mounds per unit area, a task that can be difficult in terms of cost (travel and person-hours), access to remote areas on the ground, and coverage of large areas. Despite these difficulties little work has been done to develop reliable sampling methods based upon remote sensing. Thus far, studies on remote sensing of fire ant mounds have relied on simple photointerpretive techniques using color, colour infrared, or black and white film (Green *et al*. 1977),

10.1071/RJ08007 1036-9872/08/030291

Fig. 1. An IFA (*Solenopsis invicta* × *S. richteri*) mound in north-eastern Mississippi pasture. Photo taken in the fall; note ring of actively growing vegetation at the mound periphery.

true colour and false colour infrared digital composites (Vogt 2004*a*), or panchromatic grey-scale spaceborne imagery (Vogt 2004*b*). These efforts have resulted in reasonably good detection rates of up to 79%, but photointerpretation is time-consuming and is not feasible for quantifying mounds over very large areas. New means of detecting fire ant mounds may be useful for regulatory purposes or for identification of infestations in remote areas for eradication programs, such as the program underway by Queensland Department of Primary Industries and Fisheries (2008). Aerial data of sufficient visual resolution for reliable IFA mound detection ($\leq$20 cm resolution) are relatively expensive (roughly $US 1.50 per acre and more depending on economy of scale), and commercial satellite systems do not offer data of sufficient visual resolution for detection of most mounds. With high resolution imagery deliverables often measured in gigabytes, data transfer and handling can be problematic. With advances in technology, however, these problems will likely be reduced over time. This paper presents the results of an initial attempt to assess the feasibility of quantifying fire ant mounds using template-based and object-based features extracted from existing truth data in aerial multispectral imagery.

Study areas and data

Aerial multispectral imagery was obtained for two study sites using a GeoScanner camera system (GeoVantage 2008). Briefly, the system consists of four discrete monochrome digital cameras with 10 nm band-pass filters centred at 450, 550, and 650 nm and a 40 nm band-pass filter centred on 850 nm. The system was flown on a Cessna 172 operated by GeoData Airborne Mapping and Measurement Inc. (2008). Mention of trade names or commercial products in this publication is for informational purposes only and does not constitute recommendation or endorsement by the USA Department of Agriculture or Automated Decisions, LLC.

The first site, Torrance Springs, was a pasture located in the red clay hills region of Mississippi, ~89°45′32″W, 33°52′29″N. It was flown on 16 April 2004 at an altitude of 1500 m for visual resolution of 0.15 m. The second site (Knox) was a pasture located in the black prairie region of Mississippi, ~88°35′15″W, 33°40′21″N. It was flown on 11 September 2005 at an altitude of 1000 m for visual resolution of 0.1 m. Both sites contain black and hybrid IFAs. At each site, a team of two workers searched 0.05 ha circular plots (n = 50 per site) on the ground for fire ant mounds within 3–4 days of the flight. Length, width, and height of mounds were measured (L, W, and H, respectively), percent of the mound obscured by emerging vegetation was visually estimated, and each mound was assessed for activity by probing it with a small stick and looking for emerging workers. Mound locations were recorded using a Starlink Invicta DGPS receiver (Starlink Inc., Austin, TX, USA) and a handheld PC with SoloField software (Tripod Data Systems, Corvallis, OR, USA). Image manipulation and analysis were conducted using ENVI (ITT Industries Inc., Boulder, CO, USA).

Classification methods, results, and discussion

Template-based features

Development of template-based features proceeded first using data from the Torrance Springs site. Template-based features involve the construction of representative image chips or templates using existing truth data. These templates were then compared to images, and difference metrics such as mean squared error (MSE) were calculated for use in classification schemes. Mean squared error was calculated by comparing the template to the image chips containing the candidate mounds on a pixel by pixel basis. The alignment was done such that the MSE was the minimum. A similar result would undoubtedly be obtained by using cross correlation. Note that an additional dimension of search is introduced by our treatment of mound size, and this is discussed later in the paper. An example of a template for use with near infrared (NIR) imagery is shown in Fig. 2. This template resembles an idealisation of a fire ant mound as variances have been averaged out to create something that closely matches theory. Although no individual mound will exactly match this template, mound images would be expected to more closely match the template than open ground or other features. Fig. 2 illustrates the typical 'halo' of actively growing vegetation often present at the mound periphery during cooler months of the year. The elliptical shape of the mound and orientation of the major axis closely match data gathered on the ground using a 3D laser scanner (Vogt 2007).

Many of the difficulties associated with template-based features were not an issue with our chosen domain. Specifically, template-based features typically encounter problems dealing with rotation. To deal with this problem one might choose multiple templates representing various rotations, conduct some form of a search across angles, or use rotationally invariant templates (Mahalonobis and Vijaya Kumar 1997). As demonstrated by Vogt *et al*. (2004) and Vogt (2007), however, fire ant mounds in the USA are oriented with the major axis extending in a north–south direction and as such are not encountered at varying rotations. A more difficult issue, however, arises in variations due to scale. In typical applications, scaling issues are introduced because of varying distances from the sensor to the target. In our study, scale dependency issues arose due to varying sizes of ant mounds, which may be compounded by phenomological variations related to mound size. For instance, larger mounds are likely to have brighter NIR halos, presumably due to increased soil turnout and increased insolation (J. T. Vogt, unpublished data). Differences may also vary with season, terrain, and other relevant scene variables. These were the primary issues we focused on in this initial effort.

We developed elastic templates for the purposes of classification. In this manner, templates were scaled over a range of feasible mound sizes (determined during ground sampling). All sizes of templates were compared at every possible mound location, and the best (minimal distance) match was noted among the candidate templates. We were then able to create a classification feature which was reasonably invariant to mound size with the caveats noted above. We applied this method to the Torrance Springs dataset, obtaining a probability of detection (producer accuracy) of 79% with what was judged to be a reasonably small number of false positives using a linear classifier

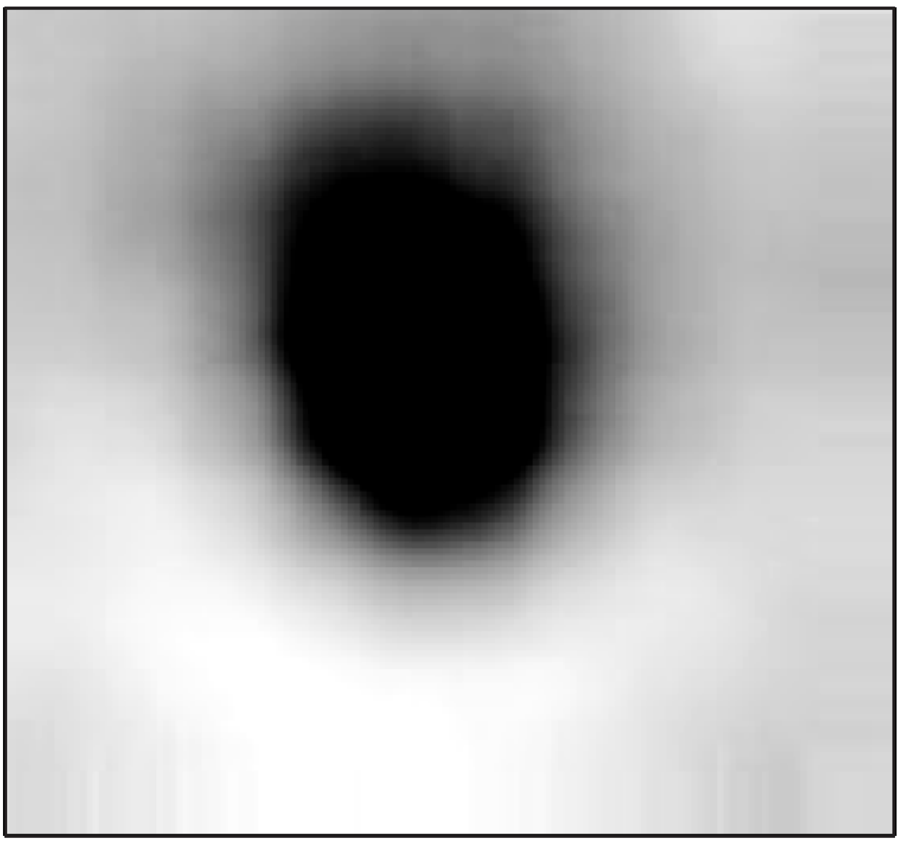

Fig. 2. Near-infrared template constructed by scaling and aligning 50 representative fire ant mounds. These chips were then averaged to create a template for locating fire ant mounds in aerial imagery.

and a leave-one-out cross-validation (Devijver and Kittler 1982). This method, however, demonstrated a failing with regard to past work because probability of detection has little meaning without a corresponding measure of false positives. An arbitrarily high probability of detection can be achieved by setting the classification threshold sufficiently low, but doing so also creates an arbitrarily high rate of false positives.

False positive rates

The problem arose in how to define a false positive rate. The ratio of false positives generated by an algorithm may be easily calculated, but the definition of the denominator is often problematic. In the case of detecting fire ant mounds, the definition of the possible false positives that were rejected was non-obvious. We chose to solve this problem by using a broad, generally admissive method for candidate mound detection. The NIR image was thresholded based upon grey scale value. This resulted in a binary (black and white) image. Mathematical morphology operations (Heijmans 1994) were applied to detect objects (contiguous, on pixel groups) of the size appropriate to mounds. Candidate mounds found in this manner that were not actually mounds were designated as potential false positives. We defined the false positive rate as the number of detected false positives divided by the number of potential false positives. Using this method our 79% detection rate had a corresponding false positive rate of 9%. The calculated receiver operating characteristic (ROC) curve is shown in Fig. 3. Accuracy assessment methods were similar to those used by Wallet *et al.* (1997).

Object-based features

In an attempt to improve detection, we investigated the integration of additional, object-based features. Object-based feature extraction tools were integrated into a newly constructed graphical browser for use in ENVI. We calculated a broad range of features, then used graphical visualisation techniques to explore the relationship between features and mound identity (Wallet and Vogt 2005). The use of exploratory data analysis allowed us to build a quadratic classifier (Duda and Hart 1973) incorporating object compactness and object symmetry. This classifier involved modelling the features as multivariate normal distributions with both target and false positive having distinct means and covariances. Classification was then performed using a likelihood ratio test. In this manner, we maintained the 79% probability of detection while reducing the probability of false positive to 4% (Fig. 3).

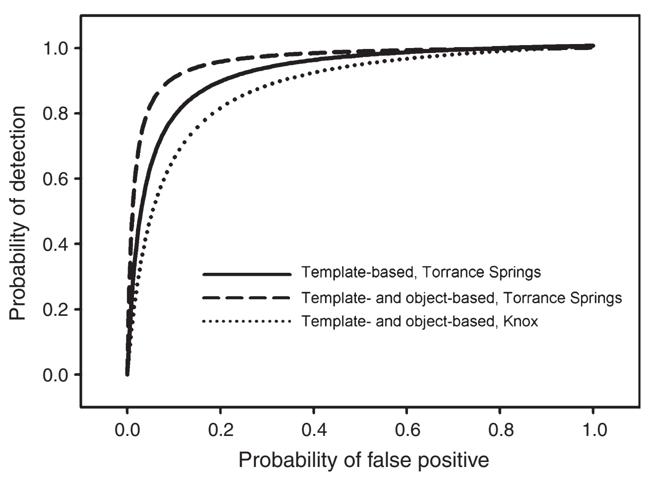

Fig. 3. Receiver-operating curves for probability of IFA mound detection using template- and object-based detection methods at two study sites. Detection algorithms were developed using truth data from the Torrance Springs site (solid and dashed lines), then applied to a novel dataset from the Knox site (dotted line).

The level of detection demonstrated using the Torrance Springs dataset represents a significant improvement over previous work, but the results were based on training and classification using the same imagery in a relatively homogeneous background. We applied the constructed classification system from the Torrance Springs dataset to the Knox dataset; this involved similar settings, but different seasonal, temporal, and other environmental factors. The result was substantially degraded performance. Maintaining the original probability of detection of 79%, the false positive rate increased to 17.5% using the previously constructed quadratic classifier. The resulting ROC curve (Fig. 3) is flatter than the previous ones, indicating a faster increase in false alarm rate as detection rates increased.

Conclusions

Template-based and object-based classification can be used to detect fire ant mounds in aerial multispectral imagery. A false positive rate of ~17.5% with a 79% probability of detection as demonstrated over the Knox site might be acceptable under some circumstances but additional work is needed to develop adaptive techniques for application in varied background types and under different environmental conditions. A probability of detection better than 80% may not be feasible, as some mounds will be too small to detect even with careful photointerpretation (Vogt 2004*a*). This work represents the first attempt at automated detection of fire ant mounds, demonstrates feasibility, and sets the stage for future efforts to construct widely applicable classifiers for use over multiple sites or to apply more specific classifiers for repeated use over a single site. The latter application would potentially be useful for tracking long-term population density fluctuations following the introduction of classical biological control agents, and the former may be useful for monitoring and detection in support of regulatory or eradication programs.

Acknowledgements

This work was supported by a Phase I Small Business Innovation Research Grant, United States Department of Agriculture, Cooperative State Research, Education, and Extension Service. We thank Mr Steven Coy for expert assistance in the field. Allan Showler and E. Raymond Hunt, Jr. provided many helpful comments on an earlier version of the manuscript.

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Manuscript received 25 January 2008; accepted 19 March 2008